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GROUND RADON SURVEY OF A GEOTHERMAL AREA IN HAWAII

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Abstract. Rates of ground radon emanation, in the Puna geothermal area on the lower east rift of Kilauea volcano, were measured by alpha particle sensitive cellulose nitrate films. The survey successfully defined an area of thermal significance associated with the rift structure, and suggests that a thermally driven ground gas convection system exists within, and peripheral to, the rift. This type of survey was found suitable for the basaltic island environment characteristic of Hawaii and is now used in Hawaii as a routine geothermal exploration technique.

Introduction

To assist in detecting potential geothermal areas in Hawaii, ground radon emanation surveys are being conducted as part of the Hawaii Institute of Geophysics' geothermal investigation. It was considered that a technique that measures a vapor phase would overcome some of the difficulties found in applying other exploration techniques, both geophysical and geochemical. To determine whether radon emanometry was applicable to Hawaii conditions, a preliminary survey was conducted in the Puna area on the lower east rift of Kilauea volcano on the island of Hawaii. This part of the rift zone last experienced eruptive activity in 1960; a geothermal well, HGP-A (1950 m deep with a maximum temperature of 358°C) verifies the existence of a geothermal fluid reservoir [Kroopnick et al., 1978]. The field survey reported here was carried out during the summer of 1978.

Background

The association of radioactivity with many geothermal and volcanic fluids is well established [Belin, 1959; Björnsson, 1968; O'Connell and Gilgan, 1978; Whitehead, 1978]. Specifically, radon gas within geothermal fluids discharged from drillholes has been used to determine reservoir hydrology in geothermal fields [D'Amore, 1975; Kruger et al., 1977]. Surface surveys of ground radon have shown an association between higher emanation and faulting in geothermal locations [Wollenberg, 1975; Nielson, 1978]. In Hawaii the technique is utilized in both preliminary and detailed surveys on the premise that the higher relative emanation of radon gas can delineate zones of thermal and structural significance in which there is greater upflow of ground gas.

Studies in continental areas suggest that uranium is being concentrated in secondary minerals in geothermal systems in that environment [Wollenberg, 1975]. Although it is not possible on the basis of available evidence to determine the degree of this type of enrichment in hydrothermal systems in Hawaii, the indication is that some concentration does occur. In the Hawaii environment the concentration of parent nuclides is low; uranium in the tholeiitic basalts of the survey area ranges from 0.1 to 0.57 ppm and thorium from 0.45 to 1.69 ppm [Fankhauser, 1976; Tatsumoto, 1978]. The radon emanation from secondary mineralization ($CaSO_4$) scraped from HGP-A well casing at 993-m depth, is similar to that from slightly weathered basaltic overburden. Sublimates (?gypsum) deposited near the 1971 fissure in Kilauea Crater have a U content of 0.44 ppm and Th of 1.19 ppm. The radon content of steam from HGP-A has a range of reported values of 0.76 to 2.40 nCi/ℓ [Kruger, 1977]. Computing a conversion factor from Mogro-Campero and Fleischer [1977], 1 nCi/ℓ = 9722 $T \cdot 10^{-2}/cm^2/hr$ (units); this gives a radon concentration in the steam approximately equivalent to 7389 to 23,333 units (see Method).

The ground radon measured in this study is considered to be essentially the isotopes ^{222}Rn (^{238}U series; half-life 3.825 days) and ^{220}Rn (^{232}Th series; half-life 54.5 sec); the major source of these isotopes is presumed to be the radioactive decay of ^{238}U- and ^{232}Th- derived radium within the lava pile above the water table. In the Puna area, the thickness of lava above the water table is from about 80 to 314 meters. Because of the very short decay period of ^{220}Rn, it is thought that the contribution of this isotope to the total radon being measured is significantly less than that of ^{222}Rn, and that it is derived entirely from sources closer to the surface.

Method

This survey utilized existing road systems, and measurement sites were spaced 1 to 1.5 km apart. Radon emanation was measured with alpha particle sensitive cellulose nitrate films [Fleischer et al, 1972]. Cardboard mounted strips of commercially produced film (Kodak, LR115, II) were suspended within inverted 250 mℓ polypropylene cups that were buried at depths of 30 to 40 cm. This is the maximum soil depth in this area, where much of the surface is formed of slightly weathered basalt lava flows. The field exposure time was 4 to 5 weeks, a period considered long enough to overcome many of the short-term fluctuations in emanation such as are caused by meteorological, diurnal or minor seismic variations.

The films were developed in the laboratory by etching in a constant temperature (60°C) bath of 2.5 N NaOH. Each batch of film was developed with a standard film that had been exposed to an ^{241}Am source. Alpha particle tracks on the films were counted visually under 100x magnification over a film area of 1 cm. The number of tracks per square centimeter is related to field exposure time and is reported in units of T (tracks) $\cdot 10^{-2}/cm^2/hr$. Samples representing the different types of surface material within the

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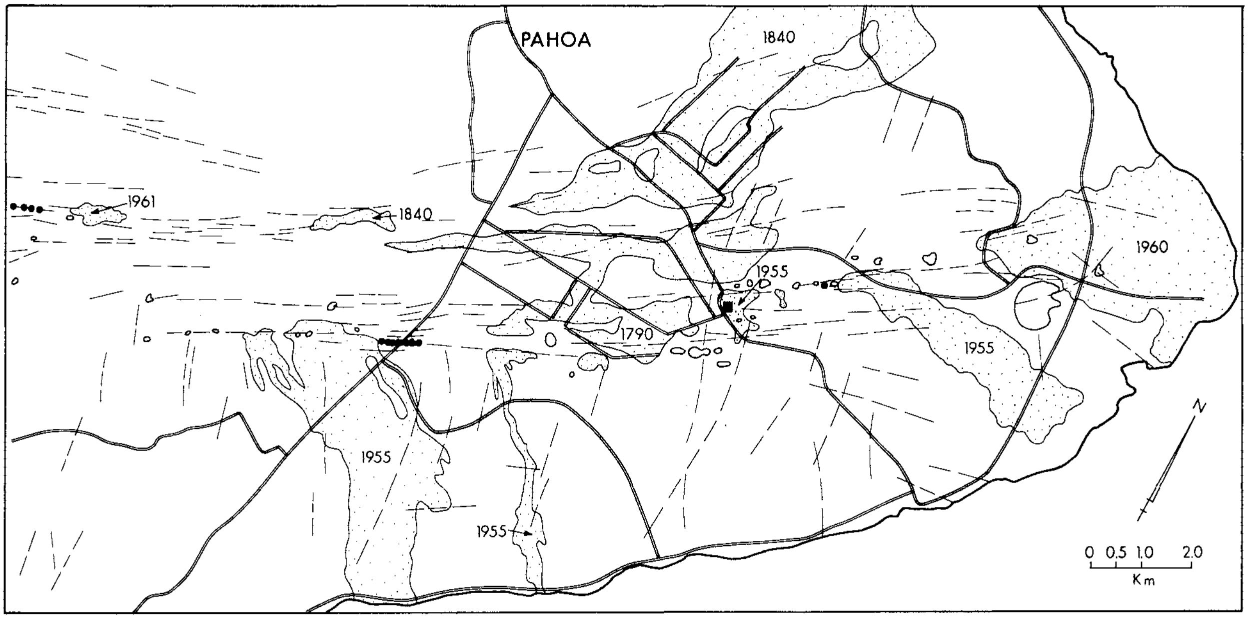

Fig. 1. Air photo lineations, eruptive features and historic flows, Puna geothermal area, island of Hawaii. The steaming areas (closed circles) are those observed during this survey. Geothermal well HGP-A is shown by a square; main roads by double lines.

area were collected and the radon emanation from these was determined in the laboratory by using a constant volume of soil (30 cm^3) placed in a capped, inverted cup. Measurements on replicate samples with this configuration had a mean standard deviation of 10%. This value of background emanation for each surface material type is also related to film exposure time and subtracted from field measurements. The resultant value is considered to be radon emanating from sources deeper than the immediate vicinity of the cup, and the data plotted in this manner indicate the features of radon outgassing. The error of corrected values was determined experimentally by setting up quadruplicates of films at different stations (two films in each of two cups). The observed variation of the corrected values at each site was approximately ± 1 unit.

For the purpose of determining background emanation from the soil, the surface material in this area was divided into five types. As the soil is derived from lavas of similar petrochemistry, the variation in radon emanation from the soil is indicated to be a function of the degree of weathering or alteration. Wilkening [1974] determined that the ^{222}Rn flux from thin organic soils over old flows on Hawaii is 6.7 times that from barren lava flows. The values used for the background of the different overburden types are: 0.92 units for fine-grained lava and spatter fragments, 1.24 units for very thin soils with a high proportion of fragments, 2.15 units for thin soils with minor organics, 5.12 units for dark organic-rich soils and 8.17 for "clayey" hydrothermally altered material. No attempt was made to distinguish the different isotopes of radon being measured [e.g. Fleischer and Mogro-Campero, 1979], as this application is based on the relative variations of total radon emanation within an area.

The survey covered approximately 170 km^2 and was centered over an area in which a geothermal reservoir is associated with an active rift zone. The lateral extent of fracturing associated with the rift is indicated by airphoto lineations and eruptive features (Fig. 1). These data suggest that the structure of this lower part of the rift is up to 4 to 5 km in width; this is wider than indicated by the location of cinder cones and pit craters. The active part of the rift, and that which has the greatest structural permeability, is along the trend of the eruptive activity (1955, 1960) and several areas of fumaroles and steaming ground can be found along its length. Several faults and fractures transect the rift.

The contour map of the corrected radon values (Fig. 2) shows a predominant zone of high positive values along the active part of the rift, suggesting anomalously high outgassing of radon. The highest corrected measurement of ground radon emanation, 53.2 units, is 24 times higher than the mean emanation from the most common "soil" type in the area. A value of 62.4 units was measured by a film suspended 2 m down Geothermal Test Well 3; the near-surface air temperature in the well was 25.5°C, and the water table is at a depth of 172 m with a temperature of 92°C. A film similarly suspended in Geothermal Test Well 2, which was violently discharging steam (88°C), was destroyed by the high temperature. This linear zone of outgassing is flanked by areas of low positive and negative values. The most negative value was -4.0 units. It should also be noted that in surveys currently being conducted over areas of alkalic basalt lavas, the radon emanation rate is 3 to 6 times higher than for tholeiitic lavas.

Also of interest is the zone immediately west of HGP-A, where more detailed measurements

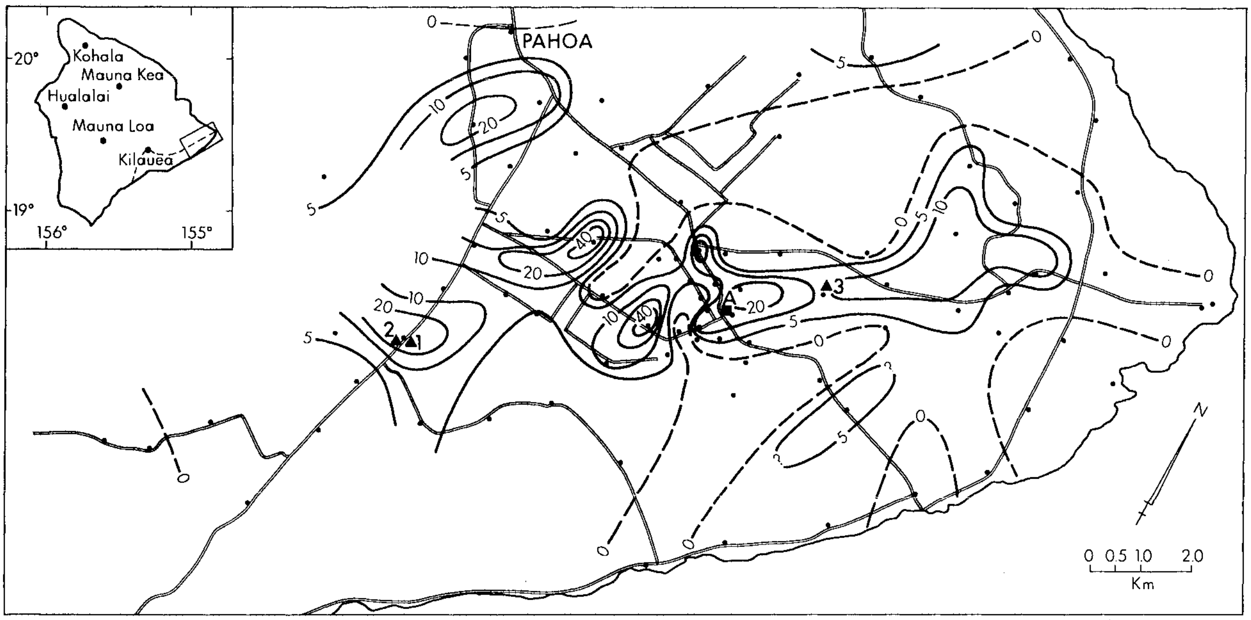

Fig. 2. Rates of ground radon "outgassing", corrected for surface material emanation. The units are $T \cdot 10^{-2}/cm^2/hr$ and the contours are at 0, 5, 10, 20 and 40 units. Measurement locations are shown by closed circles; HGP-A by a square; Geothermal Test Wells 1, 2 and 3 by triangles (these three wells were drilled in 1961). Inset shows location of survey area, volcanoes on the island of Hawaii, and the rift zones of Kilauea.

indicate a narrow, low positive-negative zone presumably associated with transverse faulting. The existence of an anomalous structure in this locality is also suggested [Zablocki and Koyanagi, 1979] by the offset of the eruptive features, as well as by seismic, magnetic and self-potential data.

Discussion

The areas with values of 5 units or greater are interpreted as defining zones of both high subsurface temperature and structural permeability, allowing ground gas movement ("outgassing") that is detectable near the surface. This vapor phase is considered to be both steam and heated ground air that act as transport media for radon gas formed at relatively shallow depth. It is proposed, however, that in those zones where the permeability and porosity are high and where the fracture permeability is continuous with depth, high upward flow rates of hot vapor exist that can transport an appreciable volume of radon over vertical distances of several hundreds of meters. Of significance here is that only 75% of an initial amount of ^{222}Rn decays in a period of approximately 7.5 days.

The peripheral negative and low positive zones are interpreted as being due to lower permeability and suggest areas in which most of the ground air is essentially static or is in some cases descending. These low values are likely also to be related to hydrogeological conditions but suggest that within the rift and peripheral areas a thermally-driven convection system has developed. Thermally induced ground gas convection has also been suggested by radon and mercury surveys over structures of volcanic origin in other parts of Hawaii. These structures include linear rift zones as well as the rim of an eroded, extinct caldera in west Oahu [Cox et al, 1979]. Convective movement of radon in the ground has also been proposed to exist in other environments where geothermal activity does not occur in the immediate vicinity [Tanner, 1964; Mogro-Campero and Fleischer, 1977]; lower magnitude thermally induced convection is a possibility in these cases due to the existence of an elevated geothermal gradient or a localized thermal anomaly.

As radon gas is being used to measure a dynamic process, the resultant anomalies are considered to approximately define the maximum extent of the subsurface thermal area by locating structures that are continuous with it. An obvious consideration, however, is whether the structures are dipping or near-vertical, and the consequent offset that the surface anomaly may have relative to the subsurface heat source. Also significant is the relationship between width of the permeable zone and the density of measurement locations. This factor would appear to be more important in an area where a single fault may be acting as the thermal fluid channel than in the present situation of a wider zone of permeability. Nielson [1978] has successfully utilized similar radon emanometry with closely spaced measurement locations along tranverses to locate buried faults continuous with a geothermal reservoir in continental terrain.

The results of this survey are consistent with a model of a geothermal reservoir that is elongate and rift-confined by both high fracture intensity and dike-impoundment of groundwater. There is some indication of a further zone of outgassing in the north of the survey area, which is in broad agreement with the concept in which the major rift structure is dipping seaward (southward) and a graben-like structure has developed between two zones of faulting and fracturing [Moore and Krivoy, 1964].

Conclusions

The use of radon emanometry for geothermal exploration has been found to be highly satisfactory in a basaltic island environment such as Hawaii. This and subsequent surveys, both reconnaissance and detailed, demonstrate that the radon emanometry technique can define thermal areas associated with structural permeability. These are the most important prerequisites for the formation of a geothermal fluid reservoir in this environment.

The results further suggest the existence of thermally driven convective systems associated with volcanic structures. The application as described has been successful in both currently active areas and those in which volcanic activity has ceased and a more complete soil profile has developed. The technique was both inexpensive and easy to implement.

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References

Belin, R. E., Radon in the New Zealand geothermal regions, Geochim. Cosmochim. Acta, 16, 181-191, 1959.

Björnsson, S., Radon and water in volcanic gas at Surtsey, Iceland, Geochim. Cosmochim. Acta, 32, 815-821, 1968.

Cox, M. E., J. M. Sinton, D. M. Thomas, M. D. Mattice, J. P. Kauahikaua, D. M. Helstern, and P-f. Fan, Investigation of geothermal potential in the Waianae caldera area, western Oahu, Hawaii, Assessment of Geotherm. Resour. Hawaii, 2, Hawaii Inst. Geophys. Rep. HIG-79-8, 101 pp., 1979.

D'Amore, F., Radon-222 survey in Larderello geothermal field, Italy, Geothermics, 4, 96-108, 1975.

Fankhauser, B. L., Thermoluminescence dating applied to Hawaiian basalts, M.S. Thesis, Dept. of Chemistry, Univ. Hawaii, Honolulu, 188 pp., 1976.

Fleischer, R. L., H. W. Alter, S. C. Furman, P. B. Price, and R. M. Walker, Particle track etching, Science, 178, 255-262, 1972.

Fleischer, R. L., and A. Mogro-Campero, Radon enhancements in the earth: Evidence for intermittent upflows?, Geophys. Res. Lett., 6, 5, 361-364, 1979.

Kroopnick, P. M., R. W. Buddemeier, D. Thomas, L. S. Lau, and D. Bills, Hydrology and geochemistry of a Hawaiian geothermal system: HGP-A, Geotherm. Resour. Explor. in Hawaii, 4, Hawaii Inst. Geophys. Rep. HIG-78-6, 64 pp., 1978.

Kruger, P. Preliminary evaluation of results HGP-A, Puna, HI radon test, July 19, 1977, Prog. Rep. Civil Engineering Dept., Stanford Univ., California, 9 pp., 1977.

Kruger, P., A. Stocker, and A. Umana, Radon in geothermal reservoir engineering, Geothermics, 5, 13-19, 1977.

Mogro-Campero, A., and R. L. Fleischer, Subterrestrial fluid convection: A hypothesis for long distance migration of radon within the earth, Earth Planet. Sci. Lett., 34, 321-325, 1977.

Moore, J. G., and H. L. Krivoy, The 1962 flank eruption of Kilauea volcano and structure of the east rift zone, J. Geophys. Res., 69, 10, 2033-2045, 1964.

Nielson, D. L., Radon emanometry as a geothermal exploration technique; theory and an example from Roosevelt hot springs KGRA, Utah, Rep. Earth Sci. Lab., Univ. Utah Res. Inst., ESL-14, 31 pp., 1978.

O'Connell, M. F., and G. A. Gilgan, Radioactivity associated with geothermal waters in the western United States, Tech. Note, Office Radiat. Prog., U.S. Environ. Protect. Agency, Las Vegas, Nevada, ORP/LV-75-8B, 25 pp., 1978.

Tanner, A. B., Radon migration in the ground: A review, in The Natural Radiation Environment, J. A. S. Adams and W. M. Lowder (eds.), Univ. Chicago Press, Chicago, 161-178, 1964.

Tatsumoto, M., Isotopic composition of lead in oceanic basalt and its implication to mantle evolution, Earth Planet. Sci. Lett., 38, 63-87, 1978.

Wollenberg, H. A., Radioactivity of geothermal systems, Second U.N. Symp. Devel. Use Geotherm. Resour., 1283-1292, 1975.

Whitehead, N. E., Radon in geothermal discharges at Broadlands, Geotherm. Circul., MKS-2, Dept. Sci. Ind. Res., New Zealand, 1978.

Wilkening, M. H., Radon-222 from the Island of Hawaii: Deep soils are more important than lava fields or volcanoes, Science, 183, 413-415, 1974.

Zablocki, C. J., and R. Y. Koyanagi, An anomalous structure in the lower east rift zone of Kilauea Volcano, Hawaii, inferred from geophysical data, in Hawaii Sympos. Intraplate Volcanism and Submarine Volcanism, Hilo, HI, 16-22, July, Abstr., 177, 1979.

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